OFF-AXIS PARABOLIC REFLECTOR

BACKGROUND

[0001] The present invention relates to the lighting arts. It especially relates to illuminators, spot lights, overhead lamps, and other light sources that employ a plurality of light emitting diodes, and to reflectors for such light sources, and will be described with particular reference thereto. However, the invention will also find application in conjunction with light sources that employ a plurality of light emitting elements other than light emitting diodes, such as miniature lamps, semiconductor lasers, and the like. The invention will still further find application in conjunction with reflectors for such other light sources.

[0002] Conventional parabolic reflectors are designed for use in conjunction with a single, high brightness light emitting element such as an incandescent filament. The high brightness light emitting element is placed at a focal point of the reflector, and the parabolic reflector geometry causes light rays emanating from the focal point to be directed outward from the reflector opening or aperture as a generally collimated beam of light. Some beam divergence, which may be desirable for certain applications, can be obtained by arranging the incandescent filament in a "defocused" position a selected distance away from the focus. Moreover, a spherical reflector or other generally collimating reflector may be used instead of the parabolic reflector. A spherical reflector does not provide complete collimation, and so the beam produced using a spherical reflector has some divergence.

[0003] Existing light emitting diodes are generally not as bright as incandescent filaments. To produce a high brightness light source using light emitting diodes, it is generally advantageous to employ a plurality of light emitting diodes whose combined light output is comparable to or exceeds the output of a single high brightness incandescent filament. Replacing the incandescent filament with light emitting diodes has certain advantages, such as improved distribution of heat dissipation, higher reliability, and improved ruggedness of the light source.

[0004] However, the parabolic reflector commonly used for incandescent lamps is difficult to adapt for use with a plurality of light emitting elements. This is because it is difficult to arrange all the light emitting elements close to the focal point of the parabolic reflector. Those light emitting elements that are arranged some distance away from the reflector focus are not well collimated by the parabolic, spherical, or other generally collimating reflector.

[0005] One approach to addressing this problem is to provide a separate parabolic reflector for each light emitting diode. Each light emitting diode is arranged at the focal point of its corresponding reflector, so that the light from each light emitting diode is formed into a collimated beam of light. However, this arrangement usually produces a granularized illumination made up of a plurality of collimated "beamlets" corresponding to the plurality of light emitting elements. Such granularized illumination may be undesirable for certain applications. Moreover, the individual reflectors are arranged in an array or other closely packed configuration to provide cumulative illumination. Such an arrangement may present manufacturing difficulties.

[0006] The present invention contemplates an improved apparatus and method that overcomes the above-mentioned limitations and others.

BRIEF SUMMARY

[0007] According to one aspect, A reflector is disclosed. A sidewall defines a perimeter surrounding an interior region. A plurality of intersecting curved reflective surfaces are disposed in the interior region. Each curved reflective surface defines an off axis reflector segment having a focus disposed at the perimeter and oriented to reflect light emanating from its focus out a reflector aperture defined by the sidewall.

[0008] According to another aspect, an apparatus is disclosed. A generally concave reflector includes a plurality of off axis reflector segments. A plurality of light emitting elements correspond to the plurality of off axis reflector segments. Each light emitting element is disposed at a focus of a corresponding off axis reflector segment and is arranged to illuminate that segment.

[0009] According to yet another aspect, a lamp is disclosed. A reflector includes a plurality of off-axis reflector segments each having a focus at a perimeter of the reflector. A plurality of light emitting elements are disposed at the foci of the off-axis reflector segments.

[0010] Numerous advantages and benefits of the present invention will become apparent to those of ordinary skill in the art upon reading and understanding the present specification.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The invention may take form in various components and arrangements of components, and in various process operations and arrangements of process operations. The drawings are only for purposes of illustrating preferred embodiments and are not to be construed as limiting the invention.

[0012] FIGURE 1 shows a perspective view of a generally circular reflector.

[0013] FIGURE 2 shows a cross-sectional side view of the reflector of FIGURE 1.

[0014] FIGURE 3 shows a perspective view of a light source including three light emitting diodes and the generally circular reflector of FIGURES 1 and 2.

[0015] FIGURES 4A, 4B, 4C, and 4D show conceptually how the reflector of FIGURES 1 and 2 is designed.

[0016] FIGURE 5 shows a top view of a linear light source including a plurality of light emitting diodes and a rectangular reflector.

[0017] FIGURE 6 shows a thin cross-sectional slice of the linear light source of FIGURE 5. The thin slice **S** is indicated by dotted-dashed lines in FIGURE 5.

[0018] FIGURE 7 shows a top view of a square light source including four light emitting diodes and a square reflector.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0019] With reference to FIGURES 1-3, a lamp **8** includes a generally concave reflector **10** that has a generally circular perimeter **12** surrounding an interior region **14**. Three intersecting off-axis reflector segments **20, 22, 24** are disposed in the interior region **14**. The three off-axis reflector segments **20, 22, 24** define three lines of intersection **25, 26, 27**. Intersection line **25** labeled in FIGURE 1 is defined by the intersection of reflector segments **20, 22**. Intersection line **26** labeled in FIGURE 2 is defined by the intersection of reflector segments **22, 24**. Intersection line **27** labeled in FIGURE 1 is defined by the intersection of reflector segments **20, 24**. The off-axis reflector segments **20, 22, 24** can be off-axis parabolic reflector segments, off-axis spherical reflector segments, another type of generally collimating off-axis parabolic reflector segment. The illustrated off-axis reflector segments **20, 22, 24** are substantially similar; however, the reflector segments can be different. For example, two segments can be parabolic while the third can be spherical.

[0020] With continuing reference to FIGURES 1-3, the off-axis reflector segments **20, 22, 24** each have a corresponding focus or focal position **30, 32, 34** disposed at the perimeter **12** of the reflector **10**. A sidewall **36** is disposed along the perimeter **12**. An interior surface **38** of the sidewall **36** supports light emitting elements **40, 42, 44** (shown in FIGURE 3) at about the focal positions **30, 32, 34**, respectively. In one embodiment, the light emitting elements **40, 42, 44** are light emitting diodes; however, miniature incandescent lamps or other compact light emitting elements can also be used.

[0021] The focal position **30, 32, 34** of each off-axis reflector segment **20, 22, 24** is disposed at a portion of the perimeter **12** defined by or lying along the two other reflector segments **20, 22, 24**. The focus **30** of the off-axis reflector segment **20** is disposed at a portion of the perimeter **12** defined by the off-axis reflector segments **22, 24**; the focus **32** of the off-axis reflector segment **22** is disposed at a portion of the perimeter **12** defined by the off-axis reflector segments **20, 24**; and the focus **34** of the off-axis reflector segment **24** is disposed at a portion of the perimeter **12** defined by

the off-axis reflector segments **20, 22**. The reflector **10** and the light emitting elements **40, 42, 44** together define the lamp **8** illustrated in FIGURE 3.

[0022] The light emitting element **40** at the focal position **30** of the off-axis reflector segment **20** illuminates the reflector segment **20**. In FIGURE 3, this illumination is indicated as a diverging cone of light emanating from the light emitting element **40**, and the illuminated area or footprint of the light on the corresponding off-axis reflector segment **20** is indicated. The collimated reflected beam of light is not illustrated. In similar fashion, the light emitting element **42** at the focal position **32** of the off-axis reflector segment **22** illuminates the reflector segment **22**, and the light emitting element **44** at the focal position **34** of the off-axis reflector segment **24** illuminates the reflector segment **24**. In one embodiment, the off-axis reflector segments **20, 22, 24** are parabolic reflector segments defining the foci **30, 32, 34** and the light emitting elements **40, 42, 44** are substantially point light sources precisely positioned at the foci **30, 32, 34**, respectively. In this embodiment, light emanating from each light emitting element **40, 42, 44** and illuminating the respective reflector segment **20, 22, 24** is reflected outward from the generally concave reflector **10** as a collimated beam of light. The generally circular perimeter **12** corresponds to an aperture of the generally concave reflector **10**.

[0023] In other embodiments, the collimating geometry is partially relaxed, resulting in a diverging or otherwise incompletely collimated beam of light. For example, the light emitting elements **40, 42, 44** may be defocused relative to their respective off-axis reflector segments **20, 22, 24**. Such defocusing is accomplished in one embodiment by disposing the light emitting elements a selected distance away from their respective foci **30, 32, 34**, to produce a diverging lamp illumination. The light emitting elements **40, 42, 44** in most embodiments are not perfect point light sources; rather, they generally have a finite size and thus some spatial spread of the light source. Such spatial spread also typically results in incomplete collimation and some beam divergence. Still further, the off-axis reflector segments may have a spherical or other non-parabolic configuration that does not provide complete collimation even when the light emitting elements are positioned precisely at the foci. Relaxed collimation geometries such as those just described may correspond to known

tolerances of the manufacturing. For some applications, however, a diverging beam may be desired. For these applications, a relaxed collimation geometry is intentionally employed to obtain some beam divergence.

[0024] With reference to FIGURES 4A, 4B, 4C, and 4D, a suitable conceptual approach for designing the reflector **10** is described. The design approach begins with a single conceptual on-axis parabolic reflector **60** shown in FIGURE 4A. The parabolic reflector **60** has a focus **62** lying on an axis of rotational symmetry of the parabolic reflector **60**. As shown in FIGURE 4B, the generally circular perimeter **12** is selected such that it intersects the focus **62**. A projection of the generally circular perimeter **12** onto the surface of the parabolic reflector **60** defines a segment **62a** of the parabolic reflector **60**. Also indicated in FIGURE 4B is a center **64** of the generally circular perimeter **12**, and a projection line **66** connecting the center **64** with the projection of the center **64** onto the parabolic reflector segment **60**.

[0025] As shown in FIGURE 4C, the off-axis reflector segment **20** is obtained by retaining only that portion of the segment **62a** corresponding to an angular interval α of the generally circular perimeter **12**. Because the reflector **10** includes three off-axis reflector segments **20, 22, 24**, the angle α is selected as 120°. In general, for N off-axis reflector segments in a generally circular reflector using the present design approach, the angular interval α is selected as 360°/N. Thus, when designing for four off-axis reflector segments, an angular interval of 90° would be suitable. The portion **36a** of the sidewall **36** lying along the off-axis reflector segment **20** is defined by vertical projections from the perimeter **12** to the surface of the segment **62a** of the parabolic reflector **60**. As shown in FIGURE 4D, the remaining off-axis reflector segments **22, 24** are suitably designed by rotating the off-axis reflector segment **20** by 120° and by 240° about the center **64**, respectively. More generally, for N off-axis reflector segments, the additional segments are suitably designed by rotating the first segment by 360°/N and integer multiples thereof. Thus, when designing for four off-axis reflector segments, rotating the first reflector segment by 90°, 180°, and 270°, respectively, would suitably position the other three off-axis reflector segments.

[0026] In another approach, the angular intervals for the segments are different. For three reflector segments, for example, three angular intervals of 100°, 120°, and 140° can be used. The total of the angular intervals should add up to 360° for a generally circular reflector. In such embodiments in which the angular intervals are not the same, the reflector will not have an N-fold rotational symmetry.

[0027] It is to be appreciated that FIGURES 4A, 4B, 4C, and 4D illustrate a conceptual approach for designing the reflector **10**. The reflector can be manufactured substantially in accordance with the process illustrated in FIGURES 4A, 4B, 4C, and 4D, for example by starting with a physical reflector shaped as the on-axis parabolic reflector **60**, cutting out the off-axis reflector segment **20** from that physical reflector as indicated by FIGURES 4B and 4C, repeating the process to cut out off-axis reflector segments **22, 24**, securing the three off-axis reflector segments **20, 22, 24** together by welding, brazing, or another joining technique, and forming the sidewall **36** using shaped sheet metal or another process and a suitable joining technique.

[0028] In another manufacturing approach, the reflector **10** is fabricated by injection molding using a pre-shaped mold die. For example, the reflector **10** can be formed of plastic using injection molding, followed by deposition of a metal or another reflective layer or stack of layers onto the inner surface of the concave reflector **10** using vacuum evaporation, sputtering, or another suitable deposition method. In yet another manufacturing approach, the reflector **10** is formed from an aluminum or other metal blank that is shaped into the shape of the reflector **10** using a hydroform press with a punch element corresponding to the shape of the reflector **10**. These manufacturing approaches are examples only; those skilled in the art can readily select other methods for manufacturing the concave reflector **10**.

[0029] For illumination and other applications in which a high light intensity may be desired, the light emitting elements **40, 42, 44** are suitably operated using a relatively high power input, and may dissipate substantial amounts of heat. In some embodiments, the sidewall **36**, or at least the interior surface **38** thereof, is substantially thermally conductive and provides heat sinking, or at least a thermally conductive heat removal pathway, for the light emitting elements **40, 42, 44**. In other

embodiments where the heat output of the light emitting elements **40, 42, 44** is lower, radiative cooling may be sufficient and so the sidewall **36** can be thermally insulating.

[0030] To provide convenient electrical wiring for the light emitting elements **40, 42, 44**, the sidewall **36** may include one or more printed circuit boards that support printed circuitry for feeding electrical power to the light emitting elements **40, 42, 44.** For example, planar printed circuit boards (not shown) can be mounted on the interior surface **38** of the sidewall **36**, or printed circuitry can be disposed directly onto the interior surface **38** of the sidewall **36**. In the latter arrangement, the interior surface **38** should be electrically insulating to provide electrical isolation for the printed circuitry. In still yet other embodiments, the light emitting elements **40, 42, 44** are electrically connected to wires passing through electrical vias (not shown) of the sidewall **36.**

[0031] With reference to FIGURES 5 and 6, a light strip or lamp **108** includes a reflector **110** that has a generally rectangular perimeter **112** surrounding an interior **114**. Ten intersecting off-axis reflector segments **120a, 120b** are disposed in the interior region **114**. The off-axis reflector segments **120** are arranged in two rows of five segments **120** each. The first row is made up of reflector segments **120a,** which define a long side **112a** of the rectangular perimeter **112**. The second row is made up of reflector segments **120b,** which define a long side **112b** of the rectangular perimeter **112.**

[0032] The off-axis reflector segments **120a, 120b** can be off-axis parabolic reflector segments, off-axis spherical reflector segments, another type of generally collimating off-axis parabolic reflector segment. The off-axis reflector segments **120a, 120b** each have a corresponding focus or focal position disposed at the perimeter **112** of the reflector **110**. An angled ledge **136a** disposed at or near the long side **112a** of perimeter **112** supports light emitting elements **140a** disposed at about the focal positions of the off-axis reflector segments **120b**, respectively.

[0033] The light emitting elements **140a** illuminate the reflectors **120b**, which reflect the illumination as a generally collimated beam of light. Because the light emitting elements **140a** positioned at about the focus positions of reflector segments **120b**, the

reflected light is generally collimated. However, incomplete collimation may be present, leading for example to a diverging reflected beam as illustrated by dotted lines in FIGURE 6. Incomplete collimation can be intentionally designed, for example by positioning the light emitting elements **140a** a selected distance away from the focal positions of the off-axis reflector segments **120b**, or by using spherical or other non-parabolic off-axis reflector segments that do not provide complete collimation.

[0034] In similar manner, an angled ledge **136b** disposed at or near the long side **112b** of perimeter **112** supports light emitting elements **140b** disposed at about the focal positions of the off-axis reflector segments **120a**, respectively. The light emitting elements **140b** illuminate the reflectors **120a**, which reflect the illumination as a generally collimated beam of light. Because the light emitting elements **140b** are positioned at about the focus positions of reflector segments **120a**, the reflected light is generally collimated, although some beam divergence is optionally designed into the lamp. The angled ledges **136a**, **136b** may include printed circuit boards, printed circuitry, electrical vias, or other suitable structure for electrically connecting the light emitting elements **140a**, **140b** to electrical power.

[0035] In one embodiment, the light emitting elements **140** are light emitting diodes; however, miniature incandescent lamps or other compact light emitting elements can also be used. The reflector **110** and the light emitting elements **140** collectively define the lamp **108**. While two rows each including five off-axis reflector elements are illustrated, it will be appreciated that fewer or additional off-axis reflector segments and corresponding light emitting elements can be included to produce a linear light strip of selected length.

[0036] The reflector **110** can be designed using a procedure similar to that illustrated in FIGURES 4A-4D for the generally circular reflector **10**. A suitable conceptual design approach for designing the reflector **110** is described with reference to one of the off-axis reflector segments **120b**, which has its corresponding focal position designated as focus **162** in FIGURE 5. A conceptual on-axis parabolic reflector **160** corresponding to the focus **162** is indicated in FIGURE 5 by a dashed circle. Each of the other off-axis reflector segments **120a**, **120b**, can similarly be considered to have

their focal positions designated as on-axis foci of conceptual on-axis parabolic reflectors, which will overlap substantially. The on-axis reflectors are trimmed at their intersections and are trimmed at about the generally rectangular aperture **112**. Trim lines **126** for the example on-axis parabolic reflector **160** are labeled as trim lines **126** in FIGURE 5. Once trimmed, the foci lie at about the perimeter **112** and are off-axis foci for the off-axis reflectors **120a**, **120b** defined by the trimming. For example the long side **112a** of perimeter **112** approximately passes through the focus **162** which serves as the off-axis focus for the off-axis reflector **120b** bounded by the trim lines **126**. The perimeter **112** corresponds to a rectangular aperture of the reflector **110**.

[0037] The reflector **110** can be fabricated in various ways, include sheet metal shaping, injection molding, hydroforming, and the like. When the reflector is formed of a substantially non-reflective material, a metal or other reflective coating can be deposited on the concave surfaces of the off-axis reflector segments **120a**, **120b** using vacuum evaporation, sputtering, or the like.

[0038] With reference to FIGURE 7, a lamp **208** includes a reflector **210** that has a generally square perimeter **212** surrounding an interior **214**. Four intersecting off-axis reflector segments **220** are disposed in the interior region **214**. The off-axis reflector segments **220** are arranged in a square. The off-axis reflector segments **220** can be off-axis parabolic reflector segments, off-axis spherical reflector segments, another type of generally collimating off-axis parabolic reflector segment. Each off-axis reflector segment **220** has a corresponding focus or focal position disposed at a corner of the generally square perimeter **212** across the reflector **210** from that off-axis reflector segment **220**. Light emitting elements **240**, such as light emitting diodes, miniature incandescent lamps, or the like, are disposed at about the focal positions. Each light emitting element **240** illuminates the off-axis reflector segment **220** disposed across the reflector **210** from that light emitting element **240**, as indicated by dotted lines in FIGURE 7. The light emitting elements **240** can be mounted on sidewalls, ledges, or other support structures disposed at the corners of the perimeter **212**. The light emitting elements **240** illuminate their respective off-axis reflector segments **220**, which generally collimate and reflect the light out an aperture corresponding to the generally square perimeter **212**.

[0039] The invention has been described with reference to the preferred embodiments. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

[0040] The appended claims follow: